Kinematics of Interstellar Gas in Nearby UV-Selected Galaxies Measured with *HST*/STIS Spectroscopy[1]

C. M. Schwartz, C. L. Martin[2,3]

Department of Physics, University of California, Santa Barbara, CA 93106, colleen@physics.ucsb.edu, cmartin@physics.ucsb.edu

R. Chandar, C. Leitherer

Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD 21218

T. M. Heckman

Department of Physics and Astronomy, Johns Hopkins University, 3400 North Charles Street, Baltimore, MD 21218

M. S. Oey

Department of Astronomy, 830 Dennison Building, University of Michigan, Ann Arbor, MI 48109

ABSTRACT

We measure Doppler shifts of interstellar absorption lines in *HST*/STIS spectra of individual star clusters in nearby UV-selected galaxies. Values for systemic velocities, which are needed to quantify outflow speeds, are taken from the literature, and verified with stellar lines. We detect outflowing gas in eight of 17 galaxies via low-ionization lines (e.g., C II, Si II, Al II), which trace cold and/or warm gas. The starbursts in our sample are intermediate in luminosity (and mass) to dwarf galaxies and luminous infrared galaxies (LIRGs), and we confirm that their outflow speeds (ranging from -100 km s^{-1} to nearly -520 km s^{-1} with an accuracy of $\sim$80 km s^{-1}) are intermediate to those previously measured in

[1]Based on observations made with the NASA/ESA *Hubble Space Telescope*, obtained from the Data Archive at the Space Telescope Science Institute, which is operated by the Association of Universities for Research in Astronomy, Inc., under NASA contract NAS 5-26555. These observations are associated with program GO-9036.

[2]Packard Fellow

[3]Alfred P. Sloan Foundation Fellow

dwarf starbursts and LIRGs. We do not detect the outflow in high-ionization lines (such as C IV or Si IV); higher quality data will be needed to empirically establish how velocities vary with the ionization state of the outflow. We do verify that the low-ionization UV lines and optical Na I doublet give roughly consistent outflow velocities solidifying an important link between studies of galactic winds at low and high redshift. To obtain higher signal-to-noise, we create a local average composite spectrum, and compare it to the high-z Lyman Break composite spectrum. Surprisingly, the low-ionization lines show similar outflow velocities in the two samples. We attribute this to a combination of weighting towards higher luminosities in the local composite, as well as both samples being on average brighter than the "turnover" luminosity in the $v - SFR$ relation.

Subject headings: galaxies: ISM – galaxies: kinematics and dynamics – galaxies: starburst – ISM: outflows

1. Introduction

Galaxy – galaxy encounters likely trigger a significant fraction of all galactic star formation (e.g., Kennicutt 1989; Heckman 1998). The strongest starburst events often produce galactic-scale winds, which transport metals and dust from the interstellar medium (ISM) into the galactic halo, and possibly beyond (e.g., Larson 1974; Dekel & Silk 1988, Lehnert & Heckman 1996). These outflows are thought to heat and enrich the intergalactic medium (IGM) and even the intracluster medium. Although the amount of matter permanently escaping the galaxy is still under debate, the interplay between star formation and galactic winds clearly plays a fundamental role in the evolution of galaxies. While feedback from active galactic nuclei may be important in larger galaxies (Scannapieco & Oh 2004), the deposition of energy and dispersal of metals by supernovae appear to shape the properties of smaller galaxies. In this paper, we explore the relation between outflow properties and galaxy morphology, environment, and star formation history via ultraviolet spectroscopy of local star-forming galaxies.

Understanding the large-scale movements of material from the ISM into the IGM requires a panchromatic picture because the temperature of the outflowing gas spans a broad temperature range. Winds were first recognized in emission lines from warm, photoionized gas. Recent studies have observed cold gas via UV/optical resonance absorption lines (Heckman et al. 2000, Rupke et al. 2002, Schwartz & Martin 2004, Martin 2005). The warm and cold gas is thought to be swept-up by a much hotter wind (and/or entrained in it). X-ray observations detect the portion of the hot wind around 0.8 keV and find that this hot gas

contains the metals from the supernova ejecta (Dahlem et al. 1998; Martin et al. 2002).

Much recent work has focused on absorption line studies of winds. Using the starburst itself as a background continuum source, the Doppler shifts of lines determine absolutely whether the gas is falling in (redshifted) or expanding outward (blueshifted). Moreover, unlike emission lines, whose strength scales as density squared, the strength of absorption lines are directly proportional to the column density of the ion along the sightline. Measurements for both local and distant starbursts often reveal blueshifted, interstellar absorption lines. For example, Schwartz & Martin (2004) measure outflows in nearby dwarf starbursts at speeds around -30 km s^{-1}. Heckman et al. (2000) find an average outflow speed of -100 km s^{-1} for luminous infrared galaxies (LIRGs). Martin (2005) and Rupke et al. (2002) detect outflow speeds of up to -700 km s^{-1} for two samples of ultraluminous infrared galaxies (ULIRGs). When these data for local starbursts are combined, the maximum outflow speeds measured in low-ionization lines are seen to increase with the global star formation rate (Martin 2005). The outflow speeds measured in distant starbursts (e.g. Shapley et al. 2003; Pettini et al. 2002; Swinbank et al. 2004), redshifts $z \sim 3$, appear to be consistent with this empirical velocity – SFR relation. However, this comparison implicitly assumes that Na I absorption (rest-frame optical) is tracing the same outflow structures as the low-ionization UV lines measured for the high-redshift galaxies.

Studying the kinematics of ultraviolet, interstellar lines in nearby galaxies serves several purposes. It provides a direct comparison between velocities measured from Na I and UV lines. It also increases the number of intermediate-luminosity starbursts with measured outflow velocities, which is important because the velocities from just three dwarf starbursts (Schwartz & Martin 2004) provide a lot of the leverage in the $v - SFR$ relation (Martin 2005). Additionally, the rest-frame ultraviolet (UV) spectrum includes a wealth of resonance lines that sample a broader range of ionization states than do optical resonance lines (e.g., Kinney et al. 1993; Heckman & Leitherer 1997; Heckman et al. 1998; Kunth et al. 1998; Shapley et al. 2003; Chandar et al. 2004; Vázquez et al. 2004). In principle, measurements of ultraviolet resonance lines can determine how the outflow speed varies among different temperature components of the wind. For example, Vázquez et al. 2004 suggest an increase in outflow velocity with ionization energy in a high-resolution spectrum of a local dwarf starburst, NGC 1705.

The UV cannot be observed in nearby galaxies from ground-based telescopes, so the spectroscopic capabilities of the Hubble Space Telescope provide unique data. As part of GO Program #9036, we examine UV resonance lines in Space Telescope Imaging Spectrograph (STIS) data of 17 nearby UV-selected galaxies. The least blended interstellar lines, which best constrain the gas kinematics, have first ionization energies less than that of H I. Hence,

we obtain the most information about the velocity of *cold* (i.e., $\sim 10^2$ K) and/or *warm* ($\lesssim 10^4$ K) interstellar gas, where much of the hydrogen may be neutral. In principle, hotter gas ($\gtrsim 10^4$ K) is traced by C IV, Si IV, and N V, but stellar winds superpose broad absorption in these lines, making any interstellar component difficult to disentangle (Robert et al. 1993, Heckman et al. 1998).

In this paper, we measure interstellar gas kinematics toward star clusters in a sample of nearby UV-selected galaxies. In §2, we discuss the *HST*/STIS observations, the data reduction, absorption line diagnostics, and systemic velocities. In §3 we discuss the ISM kinematics, including the kinematics of low-ionization absorption lines in individual galaxies. In §4, we examine the outflow trends across the sample, including the dependence of outflow velocity on ionization energy, rotation speed, and star formation rate. In §5 we present a composite spectrum for the sample, examine the high-ionization absorption lines, and compare the composite spectrum to the high-redshift Lyman Break Galaxy composite spectrum. The final section summarizes our results. We use heliocentric velocities and $H_o = 75$ km s^{-1} Mpc^{-1} throughout this paper.

2. The Data

2.1. Observations, Data Reduction, & Spectral Extraction

We have obtained Space Telescope Imaging Spectrograph (STIS) long-slit far- and near-UV spectra for 17 nearby starburst galaxies. We target individual UV-bright nuclear or near-nuclear (within 1 kpc of the galaxy center) star-forming clusters in the galaxies to provide a strong background continuum source, against which to see absorption. The galaxies were observed using the $52'' \times 0.2''$ longslit and the G140L (FUV) and G230L (NUV) gratings, projected onto the 25 arcsec^2 MAMA detector. This configuration provides continuous wavelength coverage from 1175 Å to 3100 Å. The STIS MAMA detectors have an average pixel scale of 0.584 (1.548) Å pixel^{-1} for the G140L (G230L) detector. The spectral resolution (FWHM), according to the STIS instrument handbook, is 8 pixels, or $0.2''$, for a fully extended source.

The galaxies in this sample were selected on the basis of high UV luminosity; this is a tracer of star-formation. The sample was selected to include a range of galaxy morphologies and metal content ($7.7 \lesssim \log(O/H)+12 \lesssim 9.2$). See Table 1 for salient properties of the sample galaxies. The young, hot stars in the clusters provide a strong UV background source against which we can see absorption by the ISM. Since these clusters are the most UV luminous, almost all of them have ages of 3-5 Myr (Chandar et al. 2004). The individual

star clusters in these galaxies are the same ones discussed by Chandar et al. (2004); they analyzed the absorption present in the stellar photospheres and winds to characterize the stellar population in each galaxy. We concentrate on the interstellar contribution to the spectra. Our sample differs slightly from the Chandar et al. (2004) sample. They include NGC 3049, NGC 5253 and Tol 89, which we do not because the data were taken with a different slit and are not part of this program.

We define dwarfs to be those galaxies with $M_B \geq -18$ (following the convention of Thuan & Martin 1981, Marlowe et al. 1997, and numerous other authors), and separate our sample into two subsets in which to study outflow kinematics: dwarfs and disks. However, since our sample is UV-selected, and thereby selected for the presence of active star-forming regions, we expect to see mergers and interactions in our sample, and the disk/dwarf classification scheme is less than perfect. To this end, NGC 5102 is anomalous, since it is a lenticular galaxy, classified as type SA0 pec (i.e., not a dwarf) but it has an absolute blue magnitude of -17.11, which would place it in the dwarf subsample. Mkn 33 and Tol 1924-416 both have $M_B <$ -18, yet they are classified in the literature as blue compact dwarfs. Because of this dichotomy in classification, these three galaxies are separated from the disk and dwarf subsamples in this paper.

The raw data files were retrieved from the *Hubble Space Telescope (HST)* archive. They were then co-added and processed through the CALSTIS pipeline, which performs global detector linearity corrections, dark subtraction, flat-fielding, wavelength calibration, and conversion to absolute flux units. We identify the same clusters as Chandar et al. (2004), and extract the spectra using the X1D package in IRAF[1]. This technique extracts a spectrum and subtracts a background spectrum, usually removing most of the geocoronal Lyα and O I λ1302 emission. The spectra were normalized by dividing each G140L spectrum by the mode of the flux between 1250 Å and 1500 Å. The G230L spectra were normalized by dividing the spectra by a third-order polynomial fit between 2000 Å and 3000 Å. Since we are interested in the kinematics of the interstellar absorption lines, we retain the highest possible spectral resolution and do not rebin the spectra.

Multiple clusters were observed in every galaxy except NGC 5102 and NGC 6764. If measured velocities for clusters in the same galaxy are the same (i.e., a difference in velocity cannot be measured within 1σ), then the individual cluster spectra are co-added to produce a single spectrum with higher signal-to-noise. This is the case in all galaxies with multiple

---

[1]IRAF (Image Reduction and Analysis Facility) is distributed by the National Optical Astronomy Observatories, which are operated by AURA, Inc., under cooperative agreement with the National Science Foundation.

clusters extracted, except for NGC 3310. When multiple cluster spectra were averaged, the instrumental resolution for the individual clusters were weighted by flux and averaged. Table 2 provides the number of clusters averaged (Col. 2), as well as the maximum offset of the clusters from the slit center in either direction (Col. 3). (The slit positions themselves are presented in Table 2 of Chandar et al. 2004.) Spatial variation of the outflows along multiple sightlines is further discussed in § 3.2.

2.2. Spectral Resolution

The spectral resolution for a point source observed with the $0.2''$ STIS slit is $\sim$0.88 Å at 1500 Å; for a source that fills the slit, the resolution is 4.67 Å. Most of the clusters in our sample are neither point sources nor do they fill the slit. We measured the cluster surface brightness profiles from the two-dimensional spectra by summing up 500 columns ($12\overset{''}{.}5$) along the slit spatially. We can equate the resulting spatial scale in pixels to an instrumental line width in Angstroms using the scale of 0.584 Å pixel^{-1} in the G140L spectra. Most clusters have an instrumental FWHM between 1.5 Å and 3.5 Å, with a median size of 2.7 Å (or 607 km s^{-1} at 1335 Å). These values (column 7 in Table 2) give a reasonable estimate for the resolution of individual cluster spectra (i.e., the instrumental width).

The instrumental width is subtracted in quadrature from the measured width; line widths for the C II λ1335 line are presented in column 8 of Table 2. For the four galaxies (NGC 1741, NGC 5996, NGC 7552, and Tol 1924-416) where we detect foreground/Milky Way halo lines, the instrumental line width is consistent with the widths in Table 2.

The wavelength calibration will be affected if the extracted cluster does not fall in the middle of the slit (along the dispersion axis). From the STIS handbook, typical wavelength calibrations are accurate to $\sim$0.2 pixels, or $\sim$20 km s^{-1} at 1500 Å. If the cluster is shifted by 1/4 of the slit width, or 2 pixels, then the wavelength calibration will be "off" by $\sim$200 km s^{-1} at 1500 Å. This shift is large enough that it is easily discernible from wavelength measurements of the stellar lines. Comparison with stellar lines in our spectra to literature values confirm that the spectra used in this work do not suffer from any obvious zero point offset in the wavelength scale.

2.3. Systemic Velocities

Once the spectra are extracted, the kinematics are examined. In order to measure the kinematics of the warm/cold gas in the ISM, we need to compare the systemic velocity of

each object with the velocity of the low-ionization lines. The values of v_{sys} for each object (i.e., the barycentric velocity combined with the rotation velocity at the cluster position) are given in Table 2. Ideally, the systemic velocity is derived from stellar lines in a high-resolution spectrum. Keck[2]/HIRES (Vogt et al. 1994) optical spectra of He 2-10, NGC 4214, and NGC 4449 provide a systemic velocity from the Mg I b-band absorption triplet, which is present in the K-type giants and supergiants in the starburst region. When high-resolution spectra of the star clusters are not available, a systemic velocity is taken from the literature/NED. Preference is given to CO and H I velocities over emission-line velocities since the CO and H I likely trace the gas in the colder molecular clouds in which the starburst occurs, while the emission lines could be coupled to an outflow or other non-stellar process. When the value of v_{sys} in the literature is not in agreement with the stellar lines seen in the UV spectrum, the stellar velocity is used; this is the case for NGC 3125, NGC 7552, and Tol 1924-416. (Stellar lines used include, but are not limited to, C III λ1427, Fe V λ1431, S V λ1502, and He II λ1640.)

2.4. Spectral Line Identification

Table 3 presents the wavelengths and ionization energies of lines measured in the spectra. Severely blended lines are noted. In the G140L/FUV grating, the best lines to use to characterize the purely interstellar gas (i.e., the least blended and strongest lines) are Si II (1260 Å), C II (1335 Å), Si II (1527 Å), and Al II (1671 Å). Although Ly α (1216 Å) is an important diagnostic line, our local spectra are contaminated by strong airglow emission from the earth's atmosphere, which makes it very difficult to disentangle/analyze the underlying Ly alpha emission and absorption from the starburst galaxy itself. The O I (1302 Å) and Si II (1304 Å) lines are blended, and the line combination can be affected by geocoronal O I emission if the background/sky subtraction is imperfect; therefore we exercise caution when fitting this line. We follow the convention of Shapley et al. 2003, and use an average wavelength for O I/Si II of 1303.27 Å for this line. The G230L/NUV spectrum contains fewer lines, which tend to be weak. Mg I λ2853, is a blend of stellar and interstellar absorption, though it is only detectable in six galaxies. The Mg II doublet near 2800 Å is largely interstellar, and is detected in nearly all the galaxies though it is often difficult to deblend the doublet lines. A multitude of blended Fe II lines are present from 2344 Å to 2600 Å.

[2]The HIRES data referenced herein were obtained at the W.M. Keck Observatory, which is operated as a scientific partnership among the California Institute of Technology, the University of California and the National Aeronautics and Space Administration. The Observatory was made possible by the generous financial support of the W.M. Keck Foundation.

The lines are all fit with Gaussian profiles using the *splot* task in IRAF. This task does not allow us to constrain the line fits (e.g., all Si II lines should have the same velocity and width), however it is a reliable method for fitting spectra at this resolution. To check the accuracy of our fitting, three galaxy spectra were also modeled with the SPECFIT program (Kriss 1994), which does constrain line parameters, and also produced an output model spectrum. The results differed by $\lesssim$20%. The lines were therefore fit with *splot*; all low-ionization interstellar line velocities were averaged to give an overall low-ionization interstellar outflow velocity.

3. Results

The results are presented in Table 2. The resulting difference between the systemic/stellar velocity and the velocity of the low-ionization lines measures the outflow velocity of the cool gas entrained in the galactic wind (if any). Twelve of the 14 galaxies with detectable interstellar absorption lines show blueshifts, and two do not. The spectra of NGC 4449, NGC 4861, and VII Zw 403 are too noisy to detect any absorption. While NGC 4214 shows an outflow based on other data (e.g., Schwartz & Martin 2004), our data do not resolve this. The other four galaxies (NGC 1741, NGC 3125, NGC 6764, and Tol 1924-416) are consistent with zero velocity (within 1-σ).

3.1. Doppler Shifts

A low-velocity Doppler shift is difficult to detect, due to the blending of lines and the modest resolution of the spectra. The accuracy with which the absorption lines can be fitted depends on the noise in the spectrum; on average, we estimate an error of $\sim$10% of the spectral resolution, or about 80 km s^{-1} in fitting the kinematic center of a spectral line. Figure 1 shows the relation between signal-to-noise ratio per Angstrom, (S/N)$_{\mathring{A}}$, and the fitting error, δv:

$$\delta v(\text{km s}^{-1}) = -1.8 \times (S/N)_{\mathring{A}} + 104 \text{ km s}^{-1} \tag{1}$$

We find that for a typical S/N of 13, the error in fitting is 81 km s^{-1}, which agrees with our estimate. For a cleaner spectrum with S/N of 30 (per pixel), the error is 50 km s^{-1}, and for a noisier spectrum with S/N of 8, the error is 90 km s^{-1}.

The velocities of all detectable interstellar lines are measured and the average outflow velocity $\Delta v_{outflow} = v_{sys} - v_{line}$ is presented in Table 2. C II λ1335, Si II λ1260, and Al II λ1671 are the only three unblended lines which are present in every spectrum. Si II λ1527,

while blended with the high-ionization C IV doublet, is detected and measured in all spectra. The C II and Si II spectra are presented in Figure 2.

We detect outflowing gas in eight of the 17 galaxies. The detection threshold of 1-σ may seem rather liberal; however, a threshold of 2-σ would decrease the detection level from eight galaxies to seven. The galaxy which does not fall into the 2-σ level is NGC 5102.

A velocity shift of about 80 km s^{-1} will be detected, particularly if it is present in multiple interstellar absorption lines. If there are multiple lines of a species (e.g., Si II λ1260, λ1527), we know those lines should have the same velocity and width. Moreover, if ions have similar ionization energies (see Table 3), the corresponding absorption lines should arise from regions of gas at similar temperatures, and therefore should be spatially coincident. The outflow velocities (and errors based on the signal-to-noise in the spectrum) are presented in column 6 of Table 2. The highest-velocity outflows are clearly blueshifted from the systemic velocity. Projection effects due to a non-zero inclination angle (column 6 of Table 1) are not considered because we do not know the opening angle of the outflow.

3.2. Spatial Variation of Outflows

The spatial variation in outflow speed along the slit is interesting since some starbursts show a more obviously global outflow. For example, many ultraluminous infrared galaxies show a coherent outflow over kpc scales (Martin 2005). Systems without an outflow observed near one cluster might show outflows along other sightlines.

At high resolution, two distinct clusters in the dwarf galaxy NGC 4214 (NGC 4214-1 and -2, separated by $\sim$ 500 pc) show different kinematics measured by optical Na D absorption (Schwartz & Martin 2004). NGC 4214-2 shows a blueshift of just -23 km s^{-1}, whereas NGC 4214-1 shows no shift at all, demonstrating the small (yet detectable and significant) differences in outflows between star forming clusters in the same galaxy. While this does not show that the outflows are tracking local chimneys from the disk, similar outflow velocities from spatially separated clusters can demonstrate the scale of spatial coherence in an outflow. Systems without an outflow observed near one cluster might show slightly different outflow kinematics along other sightlines, although at this resolution we cannot distinguish $\sim$ 20 km s^{-1}differences.

NGC 4214-2 was not observed with STIS. When NGC 4214-1 is fit with SPECFIT, the interstellar lines (C II, Al II, Si II) converge to a fit where they are blueshifted by -32 km s^{-1} $\pm$ 49 km s^{-1}. Since there is no outflow detected in the optical spectrum of NGC 4214-1, it is not surprising that the UV velocity measurement is consistent with no

outflow. While by no means conclusive, this marginally demonstrates that outflows can be localized, although within the errors the UV data of NGC 4214-1 does not rule out a slow outflow (as in NGC 4214-2).

Multiple sightlines could be investigated in He 2-10. It has two main starburst regions, A and B, which are separated by 350 pc, and shows a large outflow velocity (Méndez et al. 1999). Johnson et al. (2000) found similar outflow velocities from regions A and B. Our spectra from region A, the central starburst which contains five bright clusters, are shown in Figure 3. The regions all show similar kinematics, so we combine the spectra to increase the signal-to-noise. This is the case with every galaxy showing multiple clusters with the exception of NGC 3310.

NGC 3310 is the only galaxy which exhibits significant ($\gtrsim 1\sigma$) kinematic differences in clusters – regions A, B, and C have different outflow velocities, and are therefore examined separately. The kinematics of these regions are presented in Table 2. One of the larger and more complex galaxies we observe is NGC 3310. The STIS slit is positioned to observe three large clusters near the center of the galaxy – see Figure 4. The de-redshifted spectra of regions NGC 3310-A, -B, and -C are shown in Figure 5. The spectra of the interstellar lines (dashed/red) make it clear that not only is there a significant outflow of interstellar gas from the star-forming regions, but this outflow changes across the slit. Region A is ∼850 pc from region C, which is ∼100 pc from region B. The H I velocities are the same in Regions B and C, whereas Region A is more redshifted by 30 km s^{-1}(Mulder 1995); this is too small a velocity difference to be detected in these spectra, as discussed above. However, there are large ($\gtrsim$100 km s^{-1}) differences in the outflow speeds from these three regions, with Region A (C) being the slowest (fastest) outflow; the slowest outflow is still significantly larger (Δv = -339 km s^{-1}) than any other Doppler shift in this sample. This suggests we are observing either local outflows from different regions of the disk (rather than some global outflow), or local variations *within* a global outflow. The scale over which kinematics differ is surprisingly small – regions NGC 3310-B and -C are separated by only ∼100 pc.

3.3. Comparison to Previous Results

Previous measurements of outflow velocities from UV absorption lines are available for only three galaxies in our sample (e.g., He 2-10: Chandar et al. 2003, Johnson et al. 2000; Mkn 33 & Mkn 36: Kunth et al. 1998). He 2-10 is discussed below. The outflow velocity obtained for Mkn 33 agrees well with the measurement of Kunth et al. (1998). Mkn 36, however, does not agree: Kunth et al. (1998) find a redshift of +40 km s^{-1} whereas we find a relatively fast outflow. This may be due to the availability of many more lines in our

spectrum; Kunth et al. (1998) were only able to measure two absorption lines, O I λ1302 and Si II λ1304.

Larger galaxies with a more powerful starburst region tend to show a larger and therefore detectable Doppler shift (see §4.1 and §4.3). For example, NGC 7552 is a type SBab spiral galaxy. The STIS slit was placed across the nucleus. Figure 6 shows the absorption spectrum of this galaxy; a blueshift of -316 km s^{-1} $\pm$ 50 km s^{-1} is seen in the three unblended absorption lines. This is marginally consistent with the observations of Heckman et al. (2000), where the cold neutral medium is observed via Na D absorption, and is measured to have a blueshift of -216 km s^{-1} $\pm$ 20 km s^{-1}.

The five separate clusters in region A of He 2-10 have the same outflow velocities to within $\lesssim$ 30 km s^{-1}, (the fainter clusters have lower S/N and hence larger uncertainties). The low-ionization lines are fit with the SPECFIT program; this allows us to constrain the model fit, forcing lines of the same species to have the same velocity and width. Using the systemic velocity for this region from Mg-b absorption in high-resolution optical spectra (Schwartz & Martin 2005, in prep.), we fix the systemic velocity to be at the same redshift as the stellar (Mg-b) optical absorption. We measure an average UV low-ionization outflow speed of -170 km s^{-1} $\pm$ 8 km s^{-1} from the central starburst (commonly called Region A). This velocity is lower than the -360 km s^{-1} outflow (from C II and Si II) reported by Johnson et al. (2000). Part of the discrepancy, about 30 km s^{-1}, is due to our systemic velocities; but most of the difference is likely due to the uncertain position of the clusters in their larger aperture. In our recently obtained optical spectrum of He 2-10, the interstellar Na I absorption shows an outflow with four separate wind components (Schwartz & Martin 2006, in prep.). The highest velocity component is at $\Delta v_{Na} = -128$ km s^{-1}, which is consistent with the low-ionization UV absorption measurements presented here.

3.4. Line Widths

It is difficult to analyze the (Gaussian) full-width at half-maximum (FWHM) the same way we analyze the line velocities. When centering a line, there is usually an obvious absorption minimum, as seen in the C II spectra presented in this paper. Therefore, measuring the kinematic center of a line is generally straightforward. However, it is more complicated to accurately measure the FWHM since the multiplets are often blended with other species arising from different ionization energies and therefore possibly different gas phases. For example, Si II λ1527 (ionization energy 8.15 eV) is blended with the C IV $\lambda\lambda$1548, 1551 lines (ionization energy 47.89 eV), which often shows an extremely broad P Cygni profile. For this reason, we use the FWHM of the unblended C II λ1335 line (ionization energy 11.26

eV) to characterize the FWHM of the gas in the cold/warm phase of the ISM (see column 8 of Table 2). All references to FWHM herein imply a deconvolved, deredshifted width.

The deconvolved line widths (measured at the Gaussian FWHM) measured range from few$\times$100 km s^{-1} to $>$ 1000 km s^{-1}; these are broader than the Na D line widths seen in dwarfs (Schwartz & Martin 2004), LIRGs (Heckman et al. 2000) or in ULIRGs (Rupke et al. 2002, Martin 2005). The thermal line width is a few km s^{-1} for a gas at 10^4 K. The lines we observe are significantly broader than the instrumental resolution, although we do not know this resolution precisely. The absorption lines in the STIS spectra are not resolved.

The estimated maximum/terminal velocity we see scales roughly as $\Delta v_{outflow}+FWHM/2$; see Figure 7. (The exact fit is $0.62 \pm 0.17\times$ FWHM(C II). The profile shapes are described by a Gaussian profile. Generally, the lines get broader as the outflow velocity increases in magnitude. This is consistent with the physical picture of gas clouds being injected into a flow at the systemic velocity and being accelerated, as seen by Heckman et al. (2000). Since the instrumental FWHM comes from the spatial size of the cluster (see § 2.2), even with the largest instrumental widths we still see a non-zero FWHM in the C II line. This suggests that perhaps we are seeing a conglomeration of filaments and shells of interstellar gas at a variety of velocities, as seen in simulations (Fujita et al. 2005, in prep.), rather than a single cloud or simple shell.

4. Kinematics of the Interstellar Medium – Analysis

In Figure 8, we plot the outflow velocity Δv against the cluster age, UV slope, and metallicity. There are no obvious correlations among these parameters seen in the data, whether or not the samples are divided into sub-samples by galaxy type (i.e. dwarf or disk). Therefore, outflow velocities are likely more dependent on the potential well of the galaxy and the star formation rate than the properties of the stars in the starburst. Surface brightness, star formation rate, and/or cluster mass may be the best parameters to examine, since the outflow seems more dependent on the galactic-scale environment than the stellar population.

4.1. Rotation Speed vs. Outflow Velocity

An important query is whether or not the outflowing interstellar matter is moving fast enough to escape the gravitational potential well of the host galaxy. We can parameterize the dynamical mass and therefore the gravitational potential of the galaxies with the galactic rotation speed. The escape velocity ranges from $\sqrt{2}v_{rot}$ (minimum) up to $\sim 3v_{rot}$ (for gas

extending $\sim$ 3 kpc from the nucleus in an isothermal halo out to 100 kpc); a typical dwarf halo escape velocity is 100 km s^{-1} (Martin 1998). The resulting terminal velocities for the interstellar lines in our spectra are consistent with outflow being accelerated up to the escape velocity, but generally with no material exceeding v_{esc}. We plot the outflow velocity as a function of rotation speed in Figure 9. The galaxies are separated into subsamples as described in § 2.1; the bright nearby dwarf starburst galaxy NGC 1705 (Vázquez et al. 2004) is plotted as well.

Using the rotation speed as a proxy for halo mass, the overall trend suggests that more massive halos produce faster outflows. A least-squares fit gives a slope of 1.2 ± 0.2. The terminal velocity ($v_{term} \sim \Delta v + 0.5\times$FWHM) may exceed the escape velocity significantly in two dwarf galaxies in particular – Mkn 36 and Mkn 209. This tentatively suggests that entrained outflow material from the ISM is likely to escape from these smaller galaxies. This result agrees with the debated theoretical picture that dwarf galaxies may be more susceptible to mass loss via superwinds, simply because they have a smaller potential well (e.g., Larson 1974; Dekel & Silk 1986; Martin 1998; Ott, Walter & Brinks 2005).

As an example, the rotation speed of NGC 7552 from H I measurements is 230 km s^{-1}; we estimate the terminal velocity of the gas in the outflow is $\Delta v + 0.5\times$FWHM $\sim$ 700 km s^{-1}. This indicates that using a reasonable estimate for the escape velocity of $v_{esc} \sim 3v_{rot}$ (for an isothermal halo at 100 kpc and gas extending $\sim$ 3 kpc; Binney & Tremaine 1987), the escape velocity is $v_{esc} \sim$700 km s^{-1}, and it is not likely that the gas is moving fast enough to reach the escape velocity for the galactic potential.

4.2. Kinematics and Ionization Energy

An important objective of this work is to check the consistency of outflow speeds measured from different lines. We expect ions with higher ionization energies to trace higher-temperature gas, so hotter gas exhibits a faster outflow velocity (Vàzquez et al. 2004). This relationship agrees with the scenario of hotter, less dense gas breaking free from a starburst region and expanding outward at a higher rate than the colder, more dense gas from the ISM that is loaded into the flow (e.g., Schwartz & Martin 2004 and references therein).

High-resolution results (Vázquez et al. 2004) show a direct relationship between ionization energy and outflow velocity. In Figure 10, we show the outflow velocities for Al II and Si II versus C II velocity. Weighted least-squares fits to the Al II vs. C II data give a slope of 0.61 ± 0.13. The correlation is noisy, but the Al II-absorbing gas seems to be moving slower than the C II-absorbing gas. The Si II-absorbing gas is less conclusive, with a slope

of 0.77 ± 0.15. However, the overall trend of $\Delta v_{CII} > \Delta v_{SiII} > \Delta v_{AlII}$ is consistent with IE(C II) > IE(Si II) > IE(Al II) (where IE is the energy required to remove one electron and create the ion in question, as listed in Table 3.

Optical interstellar Na I absorption lines have been detected for three galaxies examined - NGC 4214, NGC 7552, and He 2-10, as discussed in § 3.3. The low-ionization UV lines for NGC 4214 (Fig. 11; Schwartz & Martin 2004) and NGC 7552 (Fig. 6; Heckman et al. 2000) yield velocities slightly faster than the Na I measurements, although the optical spectra constrain the outflow speed better. The UV lines provide good constraints for He 2-10, where the average of several low-ionization lines is roughly consistent that of the highest velocity component seen in the Na I spectrum. The slightly faster speeds seen from the low-ionization UV lines (as compared to Na I) are consistent with the average I.E. of the UV lines being greater than I.E. of Na I. These results show that $\Delta v_{NaI} < \Delta v_{CII}$ in galaxies where both lines are measured; this is in agreement with the absorption from different ions occurring in physically distinct regions of the outflow.

4.3. Star Formation Rate vs. Outflow Velocity

Another important parameter to investigate in relation to outflow velocity is the star formation rate (SFR). In Figure 12, we plot outflow velocity versus SFR, as measured by Hα luminosity (column 11 of Table 1), using the following equation from Kennicutt (1989):

$$\mathrm{SFR}\ (\mathrm{M}_{\odot}\ \mathrm{yr}^{-1}) = \frac{L_{H\alpha}}{1.26 \times 10^{41}}. \tag{2}$$

Although these Hα measurements were not corrected for internal extinction, the implied SFRs were found to be roughly consistent with those derived from the measured UV luminosities. In contrast, the SFRs estimated from the FIR *IRAS* fluxes in the 60- and 100-micron bands were generally significantly lower than the UV-Hα -derived SFRs. Hence we adopted the Hα estimates of the global SFR.

A general trend is apparent: overall, galaxies with a higher SFR exhibit faster outflow speeds. A simple least-squares fit gives a slope of 0.51 ± 0.59, This is consistent with the results for Na I velocity versus SFR presented in Martin (2005), and shows that UV absorption lines and optical resonance lines yield consistent results. However, defining this relation empirically would benefit from more and higher resolution spectra. Also, since the SFRs are quoted for the entire galaxy here, more insight could be gained from a comparison to surface photometry of the individual star-forming regions. The total SFR is much greater than that of the cluster(s) observed in the largest galaxies such as NGC 3310.

The galaxies in this sample are intermediate in luminosity to the dwarfs in the Schwartz & Martin (2004) sample and the LIRGs in the Heckman et al. (2000) and Rupke et al. (2004) samples. The $v - SFR$ relation of Martin 2005 predicts that velocities will level off around $10^1 - 10^2$ $M_\odot$ yr^{-1}, which is around the SFR of LIRGs. Therefore, the fitted velocities should be near or slightly less than the outflow velocities in the LIRGs; in general, they are.

5. A Local Star-forming Galaxy Composite Spectrum

To improve S/N, and study weaker lines as well as the systematic properties of the local star-forming regions, we created a composite spectrum of all the individual spectra. To produce our composite spectrum, we first shift all individual G140L spectra into the rest frame using the systemic velocities in Table 2. We then normalize each of the 16 individual spectra to the mode between 1250 Å and 1500 Å. The spectra are averaged and rebinned to a dispersion of 1 Å. The composite local starburst spectrum is presented, along with the composite LBG spectrum from Shapley et al. (2003), in Figure 13.

5.1. Kinematics of the Local Composite Spectrum

The low-ionization absorption lines are blueshifted in the local composite spectrum. While the lines are still blended due to stellar emission/absorption, there is little absorption redward of the systemic velocity, while blueward there is strong absorption. We used *splot* to fit Gaussian profiles to the low-ionization interstellar absorption lines (Si II, C II, Al II, O I/Si II) and found an average low-ionization outflow speed of $\Delta v_{outflow} = -142$ km s^{-1} $\pm$ 80 km s^{-1}.

In the composite spectrum, the higher S/N allows us to look for absorption from more highly ionized ions. There are three high-ionization lines: Si IV, C IV, and N V. N V is not present in the majority of the spectra, and when detected it is blended with Lyman α absorption and corrupted by the residuals from sky subtraction of Lyman α emission. There is no distinct interstellar absorption component in the Si IV or C IV lines. The local composite C IV and Si IV are accurately described by a Starburst99 model spectrum (1-100 $M_\odot$, 0.25$Z_\odot$ metallicity, instantaneous burst at 5 Myr; Leitherer 1999); we cannot confidently discern a high-ionization interstellar component in the composite spectrum in any high-ionization line. However, note that there is a detection of blueshifted interstellar N V, Si IV and C IV in the high-resolution spectrum of NGC 1705 (Vázquez et al. 2004); better resolution spectra of the clusters in this paper would likely yield a detection of some interstellar gas in these higher ions.

5.2. Comparison with the High-z Composite Spectrum

We compare our composite spectrum to the composite spectrum of the LBGs presented by Shapley et al. (2003). The samples differ in the number of galaxies included in the composite; Shapley et al. average 811 galaxies, whereas we only include 17 galaxies. Figure 14 shows a histogram of the UV luminosities of the two samples; the local sample (average log L_{UV}= 38.82 erg s^{-1}) does not overlap at all with the LBG sample (average log L_{UV}= 40.99 erg s^{-1}). Moreover, there is an "aperture bias" between the local and high-z samples. In the local spectrum we disproportionately weight the light from the clusters (which represent the youngest stellar population), whereas the high-z composite includes spectral features from both star-forming clusters and a diffuse "field" component. Chandar et al. (2004, 2005) discuss in detail the contribution of the more diffuse "field" population to composite spectra.

Given the differences in the two samples, the similarities between the local composite spectrum and the LBG composite spectrum are striking. First, the slopes in the low- and high-z composite spectra are remarkably similar: roughly -1.35 and -1.5, respectively (slope β between 1240 Å and 1600 Å for $F_\lambda \propto \lambda^\beta$). Using Starburst99 data (Leitherer et al. 1999), we can look at how the UV slope in a starburst changes with time. Both instantaneous and continuous bursts show a constant slope as a function of time out to $\sim$10$^{7.2}$ years, so the similar slopes are not hard to produce. The low-ionization interstellar absorption lines also show similar average outflow velocities: $\Delta v_{outflow} = -142$ km s^{-1} $\pm$ 80 km s^{-1} in the local sample, and $\Delta v_{outflow} = -150$ km s^{-1} $\pm$ 60 km s^{-1} in the LBGs.

The similarity in low-ionization outflow velocity is quite surprising since all of the galaxies that comprise the high-redshift composite spectrum have higher UV luminosity than even the most luminous member of the sample presented here. However, the velocity in the local composite is weighted towards the higher signal-to-noise spectra, i.e. the more luminous clusters, which have intrinsically higher outflow velocities. Therefore the dwarfs, with their overall lower outflow velocities, have less of an overall effect on the composite than the brighter galaxies, whose higher luminosity and higher outflow speeds are closer to that of the LBGs. While the composite outflow velocities may be similar in low-ionization lines between the two samples, the velocity *distributions* are different. Moreover, the SFRs for the two samples are both at or above than the "turnover" in the $v - SFR$ relation of Martin (2005). Thus, an increase in SFR above this level ($\sim 10^1 - 10^2$ M$_\odot$ yr^{-1}) will not result in an increase in the outflow velocity.

Further examination of the composite spectra reveals that the local lines are somewhat broader than the high-z lines. This can largely be explained by a difference in spectral resolution (local composite resolution $\sim$800 km s^{-1}, $z \sim 3$ composite resolution $\sim$600 km s^{-1}).

The lines in the local composite are also sampling a broader range in luminosity, including both galaxies with low outflow velocity and those with large outflow. The combination of these two effects produces broader lines in the local composite spectrum.

In particular, the C IV line in the local composite spectrum is broader than the absorption in the LBG composite spectrum, even after accounting for the spectral resolution. We interpret this chiefly as an effect of age and aperture (since we are looking at younger stellar populations with STIS, as described above). Both the local and high-z composite spectra show a more pronounced P Cygni-like emission component in C IV than in Si IV. It is hard to reproduce the LBG C IV shape from Starburst99 models or local starburst galaxy components, but either the "blue edge" or the emission portion can be fit with these stellar models (Chandar et al. 2003). Hence, higher resolution observations are also required to definitively detect the high redshift outflows in high ionization lines. For example, the high resolution spectrum of the lensed $z = 2.7$ Lyman break galaxy MS 1512-cB58 (Pettini et al. 2002) shows blueshifted interstellar N V, Si IV and C IV lines.

As another interesting similarity between the local and high-z composites, some weak lines which appear to be noise in one of the spectra also are present in the other. The nature of these lines (e.g. the small lines at 1467 Å, 1579 Å, or 1689 Å) is unknown, although they may be weak metal lines. Additionally, although the resolution of the composite spectra is too low to study column densities or covering factors via specific lines, the high resolution spectra of the local dwarf starburst NGC 1705 (Vázquez et al. 2004) and the Lyman break MS 1512-cB58 show similarly saturated absorption in the rest-frame UV.

6. Conclusions

We have detected many outflows of cool/warm interstellar gas in *HST*/STIS ultraviolet spectra of star-forming regions in nearby UV-selected galaxies. While the spectral resolution of the G140L and G230L gratings is modest, eight of 17 galaxies show unambiguous blueshifted absorption in low-ionization interstellar lines at velocities from -100 km s^{-1} to -520 km s^{-1}. Somewhat lower velocities are measured for three of the dwarf galaxies, but higher resolution spectra are needed to confirm these estimates as typical measurement uncertainties are $\pm$80 km s^{-1}. More massive galaxies with higher star formation rates generally host the higher velocity outflows. No redshifted interstellar absorption lines are found, which indicates a lack of inflows. That the lines are relatively broad (average C II line FWHM $\sim$ 800 km s^{-1}) is likely indicative of sightlines probing a multitude of filaments and shells as seen in numerical simulations, rather than a single shell or bubble.

In practice, the velocities presented in this paper were heavily weighted by the strong, unblended lines from C II, Si II, and Al II. Since C and Si have ionization energies between those of Na and H, it is possible that (like Na I) C II and Si II are tracing gas where a significant fraction of the H gas is neutral. We looked for velocity differences among the UV lines with mixed results. The Al II line tends to present lower velocities than the C II line. Since the ionization energy of Al is less than that of C, this result supports previous suggestions that higher ionization gas moves faster than less ionized material (Vázquez et al. 2004). The ionization energy of silicon lies between that of aluminum and carbon, but the Si II line measurements show higher velocities than the C II line towards galaxies where Al II presents lower outflow velocities. Unfortunately, the high ionization lines from C IV, Si IV, and N V are too blended with stellar lines or airglow to reliably measure an interstellar component in individual spectra (but see the composite spectrum below). We conclude that the velocities will need to be measured more precisely before any definitive statements about velocity and ionization state can be made.

To quantify spatial variations in the outflows, we measured line velocities toward all clusters intersected by the STIS longslit. For example, in NGC 4214 the Na I spectra clearly show outflow toward cluster #2 but none toward cluster #1 only 500 pc away (Schwartz & Martin 2004). We found substantial differences in outflow velocities toward 3 clusters in an outer spiral arm of NGC 3310 on scales of 100 pc and 900 pc. In contrast, large velocities are measured all across the dwarf starburst He 2-10. Indeed, in all other galaxies where multiple clusters were observed, there is no observed spatial variation in outflow speed at this resolution. Although global winds, generally associated with nuclear starbursts, have received the most attention to date, our work draws attention to the need for more measurements of localized outflows in less extreme galaxies (Schwartz 2005, PhD thesis). Hence, the STIS slit may not have covered the star clusters with outflows in some galaxies. Considering also that dwarf galaxy outflows are generally slower than our detection threshold of 1-σ, the fraction of local star-forming galaxies with cool outflows is likely higher than our statistics (eight of 17) suggest.

Studying galactic outflows in the ultraviolet facilitates direct comparison to the winds detected in high-redshift galaxies. The continuum slope of our composite spectrum for the local star-forming galaxies is indistinguishable from that of an analogous rest-frame UV spectrum for Lyman Break Galaxies (Shapley et al. 2003). The constituents of the latter sample are intrinsically brighter, but the two samples evidently have similarly young ages and average reddening. The low-ionization interstellar lines in these two composite spectra are remarkably similar with blueshifted absorption at about -150 km s^{-1}, which may reflect the flattening of outflow speeds seen as a function of SFR (Martin 2005). The lines for the local composite spectra are broader, reflecting a difference in spectral resolutions, as well as

the exclusion of the diffuse/field clusters in the local composite spectrum.

The case for slower outflows in dwarfs rests on a very limited number of measurements. The STIS G140L spectra are not well-suited to kinematic measurements of dwarf starbursts. We are interested in the upper envelope of the velocity distribution over a broad range in star formation rates or, better yet, rotation velocities. Hence, the low velocities in NGC 4214 and NGC 4670 have little impact, as do the large uncertainties for NGC 5102. The main results are the revised outflow speed in He 2-10 (-170 ± 8 km s^{-1}) and the new measurement for Mrk 33 (-200 ± 88 km s^{-1}). These galaxies help fill in the gap between dwarf starburst and LIRG luminosities and are found to be consistent with the velocity limits described by Martin (2005). The large outflow speeds in Mrk 209 and Mrk 36 are of special interest since these galaxies are not very luminous. Better measurements of dynamical mass and star formation rate are needed for these galaxies.

We thank Dr. Alice Shapley for a stimulating discussion about this work. Financial support was provided by the David and Lucille Packard Foundation and the Alfred P. Sloan Foundation. This research has made use of the NASA/IPAC Extragalactic Database (NED), which is operated by the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration. This research has made use of the NASA Astrophysics Data System abstract service.

REFERENCES

Beck, R., et al. 2002, A&A, 391, 83

Becker, R., Henkel, C., Bomans, D. J., & Wilson, T. L. 1995, A&A, 295, 302

Bell, E. F. & Kennicutt, R. C. 2001, ApJ, 548, 681

Binney, J., & Tremaine, S. 1987, Galactic Dynamics (Princeton: Princeton Univ. Press)

Bravo-Alfaro, H., Brinks, E., Baker, A. J., Walter, F., & Kunth, D. 2004, AJ, 127, 264

Buat, V., Boselli, A., Gavazzi, B., & Bonfanti, C. 2002, A&A, 383, 801

Chandar, R., Leitherer, C., Tremonti, C. A., & Calzetti, D. 2003, 586, 939

Chandar, R., Leitherer, C., & Tremonti, C. A. 2004, ApJ, 604, 153

Conti, P. S., Leitherer, C., & Vacca, W. 1996, ApJ, 461, L87

Contini, T. 1996, Ph.D. Thesis, Universite Paul Sabatier, Toulouse, France

Claussen, M. J. & Sahai, R. 1992, AJ, 103, 1134

Cox, A. N. 2000, New York: AIP Press, Springer

Dahlem, M., Weaver, K. A., & Heckman, T. M. 1998, ApJS, 118, 401

Davidge, T. J. 1989, PASP, 101, 494

Dekel, A., & Silk, J. 1986, ApJ, 303, 39

Dopita, M. A., Pereira, M., Kewley, L. J., & Capaccioli, M. 2002, ApJS, 143, 47

Eckart, A., et al. 1996, ApJ, 472, 588

Fanelli, M. N., O'Connell, R. W., Burstein, D., & Wu, C. 1992, ApJS, 82, 197

Gil de Paz, A., Madore, B. F., & Pevunova, O. 2003, ApJS, 147, 29

Guseva, N., Izotov, Y. I., Thuan, T. X. 2000, ApJ, 531, 776

Heckman, T. M. & Leitherer, C. 1997, AJ, 114, 69

Heckman, T. M. 1998, in ASP Conf. Ser. 148, Origins, ed. C. E. Woodward, J. M. Shull, & H. A. Thronson (San Francisco: ASP), 127

Heckman, T. M., Robert, C., Leitherer, C., Garnett, D. R., & van der Rydt, R. 1998, ApJ, 503, 646

Heckman, T., Lehnert, M., Strickland, D., & Armus, L. 2000, ApJS, 129, 493

Hunter, D. A., van Woerden, H., & Gallagher, J. S. 1994, ApJS, 91, 79

Hunter, D. A., van Woerden, H., & Gallagher, J. S. 1996, ApJS, 107, 739

Hunter, D. A. & Hoffman, L. 1999, AJ, 117, 2789

Johnson, K. E., Leitherer, C., Vacca, W. D., & Conti, P. S. 2000, ApJ, 120, 1273

Kandalyan, R. A. 2003, A&A, 404, 513

Karachentsev, I. D., Makarov, D. I., & Huchtmeier, W. K. 1999, A&AS, 139, 97

Kennicutt, R. C. 1989, ApJ, 344, 685

Kennicutt, R. C., Edgar, K. B., & Hodge, P. W. 1989, ApJ, 337, 761

Kinney, A. L., Bohlin, R. C., Calzetti, D., Panagia, N., & Wyse, R. F. G. 1993, ApJS, 86, 5

Kobulnicky, H. A., Kennicutt, R. C., & Pizagno, J. L. 1999, ApJ, 514, 544

Kriss, G. 1994, ASP Conf. Ser. 61, in Astronomical Data Analysis Software and Systems III, ed. D. R. Crabtree, R. J. Hanisch, & J. Barnes (San Francisco: ASP), 437

Kunth, D., et al. 1998, A&A, 334, 11

Larson, R. B., 1974, MNRAS, 169, 229

Lehnert, M. D., & Heckman, T. M. 1996, ApJ, 472, 546

Leitherer, C., et al. 1999, ApJS, 123, 3

Marlowe, A. T., Heckman, T. M., Wyse, R. F. G., & Schommer, R. 1995, ApJ, 438, 563

Martin, C. L. 1998, ApJ, 506, 222

Martin, C. L., Kobulnicky, H. A., & Heckman, T. M. 2002, ApJ, 574, 663

Martin, C. L. 2005, ApJ, 621, 227

McMillan, R., Ciardullo, R., & Jacoby, G. H. 1994, AJ, 108, 1610

Méndez, D. I., Esteban, C., Filipovìc, M. D., Ehle, M., Haberl, F., Pietsch, W., & Haynes, R. F. 1999, A&A, 349, 801

Morton, D. C. 1991, ApJS, 77, 119

Mulder, P. S., van Driel, W., & Braine, J. 1995, A&A, 300, 687

Murphy, T. W., Jr., Armus, L., Matthews, K., Soifer, B. T., Mazzarella, J. M., Shupe, D. L., Strauss, M. A., & Neugebauer, G. 1996, AJ, 111, 1025

Ostlin, G., Bergvall, N., & Roennback, J. 1998, A&A, 335, 850

Ott, J, Walter, F., & Briggs, Elias. 2005, MNRAS, 358, 1453

Pastoriza, M. G., Dottori, H. A., Terlevich, E., Terlevich, R., & Díaz, A. I. 1993, MNRAS, 260, 177

Pérez-Montero, E. & Díaz, A. I. 2004, MNRAS, 346, 105

Pettini, M., et al. 2002, ApJ, 569, 742

Robert, C., Leitherer, C., & Heckman, T. 1993, ApJ, 418, 749

Rupke, D. S., Veilleux, S., & Sanders, D. B. 2002, ApJ, 570, 588

Sauvage, M., Thuan, T. X., & Lagage, P. O. 1997, A&A, 325, 98

Scannapieco, E. D., & Oh, S. P. 2004, ApJ, 608, 62

Schwartz, C. M. & Martin, C. L. 2004, ApJ, 610, 201

Shapley, A. E., Steidel, C. C., Pettini, M., & Adelberger, K. L. 2003, ApJ, 588, 65

Stil, J. M., & Israel, F. P. 2002, A&A, 392, 473

Swinbank, A. M., Smail, I., Chapman, S. C., Blain, A. W., Ivison, R. J., & Keel, W. C. 2004, ApJ, 617, 64

Thuan, T. X., Hibbard, J. E., & Lévrier, F. 2004, ApJ, 128, 617

Vacca, W. D., & Conti, P. S. 1992, ApJ, 401, 543

Viallefond, F. & Thuan, T. X. 1983, ApJ, 269, 444

Vázquez, G. A. et al. 2004, ApJ, 600, 162

Vogt, S. S., et al. 1994, Proc. SPIE, 2198, 362

Wilcots, E. M., Turnbull, M. C., & Brinks, E. 2001, ApJ, 560, 110

van Woerden, H., van Driel, W., Braun, R., & Rots, A. H. 1993, A&A, 269, 15

Young, J. S., et al. 1995, ApJS, 98, 219

Table 1. The Sample of Galaxies

Galaxy (1)	Galaxy Type (2)	d (Mpc) (3)	v_{rot}[a] (km s^{-1}) (4)	log O/H +12 (5)	i (deg) (6)	M_B (7)	Age (Myr) (8)	β (9)	M(H I) (10^7M$_\odot$) (10)	log L$_{H\alpha}$ (11)	log L$_{UV}$ (12)	References (13)
He 2-10	BCD	9	119±10	8.9	...	-17.32	5±1	-1.01	30.5	40.28	42.74	1, 2, –, 1, 3
Mkn 33	BCD	19.5	111±5	8.4	...	-18.31	5±1	-1.84	62	41.24	42.61	4, 5, –, 6, 7
Mkn 36	BCD	6.9	43±5	7.8	...	-14.02	<1	-1.83	2	39.85	41.00	4, 8, –, 4, 7
Mkn 209	BCD	4.9	47±21	7.8	30	-13.30	<1	-2.45	4.1	39.90	40.83	9, 8, 10, 9, 7
NGC 1741	int. pair	51	...	8.2	...	-21.15	5±1	-1.35	1380	41.77	42.92	–, 11, –, 13, 12
NGC 3125	BCD	18.3	...	8.3	...	-17.81	5±1	0.62	...	40.61	42.02	–, 14, –, –, 7
NGC 3310-A[b]	SABbc pec	18	311±10	8.2	52	-20.13	5±1	-0.98	588	41.60	42.73	14, 15, 13, 14, 16
NGC 3310-BC[b]	SABbc pec	18	311±10	8.2	52	-20.13	5±1	-0.98	588	41.60	42.73	14, 15, 13, 14, 16
NGC 4214	IAB(s)m	3.6	70±10	8.2	...	-17.64	4±1	-1.20	110	≥40.40	41.23	17, 1, –, 18, 5
NGC 4449	IBm	3.6	...	7.8	51	-17.79	5±1	-2.74	135	40.65	41.19	1, 17, 17, 18, 16
NGC 4670	BCD	16	110±21	8.2	28	-17.93	7±1	-1.76	110	40.76	42.31	19, 13, 20, 20, 21
NGC 4861	BCD/Impec	10.7	54±3	7.9	82	-17.25	...	...	114	41.09	42.20	5, 1, 6, 6, 6
NGC 5102	SA0 pec	3.1	95±12	9.0	70	-17.11	55_{-37}	1.50	34	>37.93	40.72	22, 23, 22, 22, 24
NGC 5996	SBc	47	142±10	8.9	...	-20.76	4±1	-1.29	138	41.16	42.73	25, 13, –, 26, 27
NGC 6764	SB(s)bc/Sy2	32	187±23	8.7	44	-19.97	3±1	0.70	380	...	42.03	28, 25, 28, 25, –
NGC 7552	SB(s)ab	21	230±30	9.2	31	-20.36	5±1	-0.71	870	41.05	42.29	29, 13, 30, 31, 27
Tol1924-416	BCD	37	45±10	8.1	...	-19.54	<1	-2.67	300	41.84	42.95	32, 13, –, 32, 6
VII Zw 403	BCD	4.5	20±3	7.7	...	-13.77	...	...	6.9	39.27	40.46	5, 8, –, 7, 7

References. — (1) Sauvage et al. 1997, (2) Kobulnicky et al. 1999, (3) Johnson et al. 2000, (4) Bravo-Alfaro et al. 2004, (5) Davidge 1989, (6) Thuan et al. 2004, (7) Gil de Paz et al. 2003, (8) Pérez-Montero & Díaz 2003, (9) Viallefond & Thuan 1983, (10) Stil & Israel 2002, (11) Guseva et al. 2000, (12) Dopita et al. 2002, (13) Heckman et al. 1998, (14) Mulder et al. 1995, (15) Pastoriza et al. 1993, (16) Kennicutt et al. 1989, (17) Martin 1998, (18) Karachentsev et al. 1999, (19) Hunter et al. 1996, (20) Hunter et al. 1994, (21) Marlowe et al. 1995, (22) van Woerden et al. 1993, (23) Chandar et al. 2004, (24) McMillan et al. 1994, (25) Contini et al. 1997, (26) Kandalyan 2003, (27) Buat et al. 2002, (28) Wilcots et al. 2001, (29) Lehnert & Heckman 1996, (30) Beck et al. 2002, (31) Claussen & Sahai 1992, (32) Ostlin et al. 1998

Note. — Col. (2): Galaxy type is from RC3. Col. (3): Distance given assuming H$_o$ = 75 km s^{-1} Mpc^{-1}. Col. (4): Rotation speed is from the first reference in the last column. All rotation speeds are from H I measurements, and are corrected for inclination when available. Col. (5): 12 + log(O/H) is from the second reference in the last column. Col. (6): Inclination is from third reference in the last column. Col. (7): Absolute blue magnitude M_B is calculated from the RC3 magnitude B_T^0. Col. (8): H I mass is from fourth reference in the final column. Col. (9): Age is from Chandar et al. (2004). Age is based on the comparison of STIS FUV spectra with single burst STARBURST99 population synthesis models (Leitherer 1999). Col. (10): Power-law index of the UV continuum (F $\propto \lambda^\beta$) in the STIS G140L spectra over the wavelength range 1240 - 1600 Å after correcting for foreground Milky Way

reddening. β is measured to an accuracy of ± 0.01. (From Chandar et al. 2004.) Col. (11): Hα luminosity in ergs s^{-1} is from the fifth/last reference in the last column; these values are corrected for Galactic extinction and [NII] ($\lambda\lambda$6548, 6583) contamination, but not for internal reddening. Col. (12): UV luminosity in ergs s^{-1} is from *IUE* flux at 1900 Å, except He 2-10 and NGC 1741, where L_{UV} is λL_{λ} at 1500 Å, from Johnson et al. (2000) and Conti et al. (1996), respectively. To account for the UV spectral slope, β (Col. 9), we followed Bell & Kennicutt (2001).

[a]Rotation speeds are from H I rotation curves for NGC 3310, NGC 4214, NGC 4670, NGC 5102, and NGC 7552. All other rotation speeds are from Δv_{50}, the H I velocity width at the 50% level.

[b]NGC 3310-ABC are H II regions within NGC 3310. NGC 3310-A (see Figure 4) is equivalent to NGC 3310-1 in Chandar et al. (2004), while NGC 3310-B and -C are part of NGC 3310-all in that paper.

Table 2. Absorption Line Properties

Galaxy (1)	No. of Clusters (2)	Spatial Extent (3)	v_{sys} (km s^{-1}) (4)	v_{sys} source[a] (5)	$\Delta v_{outflow}$ (km s^{-1}) (6)	FWHM$_{inst}$ (Å)[b] (7)	FWHM(C II) (km s^{-1})[c] (8)	EW(C II) (Å) (9)	Reference (10)
He 2-10	5	+4.″5, -1.″2	869±3	Mg I	-170±8	2.5	1136	5.0	1
Mkn 33	2	-0.″9, -4.″1	1465±10	opt. lines	-200±88	3.8	555	2.4	2
Mkn 36	6	-0.″6, -1.″3	646±5	H I	-213±68	2.6	1203	3.4	3
Mkn 209	3	+2.″0, -2.″2	288±15	CO	-191±92	1.6	928	1.7	4
NGC 1741	4	+2.″7, -3.″1	3937±45	opt. lines	16±76	3.2	345	2.1	5
NGC 3125	1	-0.″9, -1.″2	964±73	UV lines	8±73	2.5	445	1.1	6
NGC 3310-A[d]	1	-4.″3, -4.″6	1040±12	H I	-339±72	2.9	1088	4.5	7
NGC 3310-B[d]	1	+8.″5, +8.″1	1010±12	H I	-414±82	2.9	1278	5.1	7
NGC 3310-C[d]	1	+7.″2, +7.″0	1010±12	H I	-561±83	1.9	1382	4.7	7
NGC 4214	1	-0.″8, -1.″3	304±1	Mg I	-32±49	3.3	549	2.1	8
NGC 4670	2	+2.″5, -1.″6	1070±21	H I	-65±73	3.3	527	1.6	9
NGC 5102	2	-0.″9, -1.″2	470±12	H I	-98±78	2.3	859	3.3	10
NGC 5996	2	-0.″8, -2.″9	3297±32	H I	-289±59	2.7	735	2.7	3
NGC 6764	1	-0.″8, -1.″2	2420±20	CO	-9±50	2.6	653	3.1	11
NGC 7552	2	+1.″7, +0.″9	1457±108	UV lines	-316±108	3.5	856	5.6	5
Tol 1924-416	2	+4.″6, -1.″6	2935±70	UV lines	-47±70	2.3	391	1.1	10

References. — (1) Schwartz & Martin 2005 (in prep), (2) Lequeux et al. 1995, (3) RC3, (4) Young et al. 1995, (5) Vacca & Conti 1992, (6) this paper, (7) Mulder et al. 1995, (8) Becker et al. 1995, (9) Hunter & Hoffman 1999, (10) van Woerden et al. 1993, (11) Eckart et al. 1996

Note. — The number of clusters given in Col. (2) is the number of individual cluster spectra extracted and averaged to produce the final spectrum of the region. The spatial extent given in Col. (3) is the maximum distance from the center of the slit to the clusters both above and below the center of the slit, in arcseconds. $\Delta v_{outflow} = v - v_{sys}$ given in Col. (6) is an average of all detectable ($\geq 3\sigma$) interstellar absorption lines. Since C II is the only unblended line detectable in every spectrum, its Gaussian FWHM is given in Col. (8), as it is believed to be representative of the typical absorption line. NGC 4449, NGC 4861, and VII Zw 403 were left out of this table due to very low ($\lesssim$1) S/N.

[a]Source of v_{sys} is given as one of the following: Mg I b-band (stellar) absorption lines, optical emission lines, H I 21-cm, CO lines, or UV absorption lines.

[b]The instrumental line width is measured from the two-dimensional spectra, as described in §2.2.

[c]The "actual" FWHM of C II is measured from the spectra and deconvolved in quadrature from the instrumental width, as described in §2.2.

[d]Systemic velocities for NGC 3310 are from H I velocity field maps from Mulder et al. (1995) to account for rotation, and show that the outflow velocities in different star-forming regions of NGC 3310 are certainly not identical.

Table 3. Absorption Lines of Interest

Line	λ (lab)[a] (Å)	I.E.[b] (eV)	Astrophysical Source[c]	Notes
C III	1175.65	24.38	Stellar	
N V	1238.80	77.47	Blend[d]	Blends with Ly α absorption
	1242.78	77.47	Blend[d]	Blends with Ly α absorption
C III	1247.38	24.38	Stellar	Blends with Si II λ1250
Si II	1260.42	8.15	ISM	Blends with C III λ1247
O I[e]	1302.17	0.00	ISM	Blends with Si II λ1304
Si II[e]	1304.37	8.15	ISM	Blends with O I λ1302
C II	1334.53	11.26	ISM	
Si III	1343.41	16.35	Stellar	
Si IV	1393.75	33.49	Blend[f]	Often shows PCyg structure
	1402.77	33.49	Blend[f]	Often shows PCyg structure
Si III	1417.24	16.35	Stellar	Blends with Si IV in PCyg profiles
C III	1426.80	24.38	Stellar	
Fe V	1430.57	54.80	Stellar	
S V	1501.76	47.22	Stellar	
Si II	1526.71	8.15	ISM	Blended with C IV
C IV	1548.19	47.98	Blend[f]	Often shows PCyg structure
	1550.77	47.98	Blend[f]	Often shows PCyg structure
Fe II	1608.45	7.87	ISM	
He II	1640.34	24.59	Stellar	
Al II	1670.78	5.99	ISM	
Fe II	2344.21	7.87	ISM	
Fe II	2382.77	7.87	ISM	
Fe II	2586.65	7.87	ISM	
Fe II	2600.17	7.87	ISM	
Mg II	2796.35	7.65	ISM[g]	
	2803.53	7.65	ISM[g]	
Mg I	2852.96	0.00	Blend[g]	
Na I	5889.95	0.00	ISM[h]	
	5895.92	0.00	ISM[h]	

[a]All lab (air) wavelengths are from Vázquez et al. 2004 except: C III λ1427, Fe V λ1431, and He II λ1640 (from Morton 1991); Si II λ1260 and Fe II λ1608 (from Shapley et al. 2003).

[b]The energy given as "I.E." is the energy required to remove an electron from the parent ion to create the ion listed. For example, I.E.(Al II) is the energy needed to remove an electron from neutral Al and create the Al II ion. Values are from Cox 2000.

[c]Possible sources are predominantly stellar ("Stellar"), predominantly interstellar ("ISM"), or a blend ("Blend").

[d]N V $\lambda\lambda$ 1238, 1242 is severely blended with Ly α absorption in nearly all galaxies, as is also the case with the Lyman Break Galaxies (Shapley et al. 2003).

[e]O I and Si II are blended together at our spectral resolution. We use the same average wavelength as Shapley et al. 2003: 1303.27 Å.

[f]Si IV and C IV are assumed to be blends of a P Cygni emission/absorption profile, absorption in stellar photospheres, and possibly some interstellar absorption (e.g., Heckman et al. 1998; Shapley et al. 2003; Chandar et al. 2004).

[g]Mg II is assumed to be predominantly interstellar based on the findings of Vázquez et al. 2004 wherein no stellar components were observed for these ions in a high-resolution spectrum of a nearby dwarf starburst. Mg I is present as an interstellar line in NGC 1705 (Vázquez et al. 2004), but is also commonly seen in stellar UV spectra (Fanelli et al. 1992). Since the optical Mg I triplet (5172 Å) is stellar as well, we assume this line as a blend.

[h]Data for the optical resonance doublet, Na I, also called the Na D doublet, is provided for comparison. Schwartz & Martin (2004; 2005, in prep) analyze the Na D absorption in NGC 4214, NGC 4449 and He2-10, as discussed in the text.

Fig. 1.— Uncertainty (δv) in velocity (km s^{-1}) as a function of median signal-to-noise for the spectra fit with SPECFIT: NGC 3310-ABC, NGC 4214, NGC 7552, and He 2-10. (Fitting a spectrum with SPLOT does not give a useful measurement of error.) The data are fit (dashed line) with a least-squares fit, giving a slope -1.8 km s^{-1} $\pm$ 0.2 km s^{-1}per unit signal-to-noise.

Fig. 2.— (a) Normalized, rest-frame STIS G140L spectra of the C II absorption line. The rest wavelength of C II (1334.53 Å) is marked by the dotted line. This is one of the only unblended interstellar lines which appears in all spectra. The top three rows shows C II in all the galaxies with outflows; the bottom row shows C II in the four galaxies where little or no outflow is detected. (b) The same plot, but for the Si II absorption line at 1260.42 Å. The two lines plotted illustrate the variation in velocity between lines. For example, some galaxies (e.g., He 2-10) exhibit obviously blueshifted lines with similar profiles in both C II and Si II, whereas other galaxies (e.g., NGC 4670) show differences between the two lines.

Fig. 3.— (a) Normalized STIS G140L spectra of the low ionization absorption line profiles used to measure the warm/cold gas outflow velocity in He 2-10. Top: O I/Si II λ1303 and C II λ1335. Bottom: Si II λ1263 and Al II λ1671. The solid line plotted over the data is the fit from the SPECFIT program. The dotted lines represent the wavelengths corresponding to the systemic velocity for each of the absorption lines, which are labelled with the species and ionization state. The systemic velocity used is 869 km s^{-1}, as discussed in the text; this is consistent with the stellar lines seen in this spectrum. The interstellar absorption is measured to have $\Delta v_{outflow}$ = -170 km s^{-1}. (b) Top: Same as (a), for G230L grating lines Fe II $\lambda\lambda$2344, 2374, 2383, Mg II $\lambda\lambda$2796, 2804, and Mg I λ2853. Bottom: Keck/HIRES spectra ($\sim$7 km s^{-1} resolution) of Na D $\lambda\lambda$5890, 5896. The interstellar Mg I and Mg II lines are fit to have the same blueshift of -170 km s^{-1} as the optical absorption lines (Schwartz & Martin 2006, in prep.); the optical lines are statistically well-fit (χ^2 = 0.75). The Fe II lines show smaller blueshifts, if any at all; these are blends of multiplet lines and nearby absorption in the Galactic halo and clouds.

Fig. 4.— Archival *HST*/WFPC2 F606W (MAST dataset #U2E67Q01T) image of the central region of NGC 3310, with position of the STIS slit overlaid. The star-forming regions A, B, and C are marked. Regions A and C are $\sim$850 pc apart, and regions B and C are separated by roughly 100 pc.

Fig. 5.— STIS G140L spectra of the three bright star clusters (A, B, and C) observed in NGC 3310. The spectra have been de-redshifted. The solid lines (colored blue in the electronic edition) represent the wavelengths of stellar lines, and they are Si III λ1417, C III λ1427, and S V λ1502. These are fit to check the value of the systemic velocity used. The dashed (red) lines are predominantly interstellar in origin; they are Si II λ1260, O I/Si II λ1303, C II λ1335, Si II λ1527, and Al II λ1671. These are used to fit the velocity of the gas in the interstellar medium. The dotted (green) lines are the Si IV and C IV doublets, which are blends of the gas in stellar photospheres, winds, and possibly some interstellar gas.

Fig. 6.— Normalized STIS spectra of the low ionization absorption line profiles used to measure the interstellar gas outflow velocity in NGC 7552. The solid line plotted over the data is the fit from the SPECFIT program. The dotted lines represent the wavelengths corresponding to the systemic velocity for each of the absorption lines, which are labelled with the species and ionization state. The systemic velocity is 1457 km s^{-1} (from stellar absorption lines in the G140L spectrum); this is consistent with the stellar lines seen in this spectrum. The average outflow velocity of cold/warm gas as measured by low ionization lines such as C II, Si II, and Al II is 316 km s^{-1}.

Fig. 7.— Average outflow velocity (Δv) for all interstellar absorption lines as a function of the FWHM of the C II line, which is often the only detectable, unblended, purely interstellar absorption line. The error bars are estimated from the relation between velocity fitting errors and signal-to-noise as discussed in 3.1. The solid line (black in the electronic edition) is a least-squares fit of the data which shows that FWHM $\sim 2\Delta v_{outflow}$ (actual slope of fit = 1.6 ± 0.50), as discussed in the text.

Fig. 8.— Dependence of starburst region age (top), UV continuum slope β_i (middle), and oxygen abundance log(O/H) + 12 (bottom) on outflow velocity. Age and β_i are taken from models calculated in Chandar et al. (2004); NGC 5102 has an age of 55_{-37}, and is not included in this graph for the sake of clarity. Oxygen abundances given as log(O/H) + 12 are from references given in Table 1; abundance errors are not specified. The given outflow velocities are averages of all available, unblended interstellar absorption lines (as discussed in the text). Velocity uncertainties are estimated using the signal-to-noise of the individual spectra as discussed in Section 3.1, and are given in Table 2. The filled triangles (colored red in the electronic edition) represent dwarf galaxies; the (green) filled squares represent Mkn 33, NGC 5102, and Tol 1924-416, which aren't classified as dwarfs or disks in this paper; (blue) open stars represent disk galaxies.

Fig. 9.— Outflow velocity ($\Delta v_{outflow} = v_{line} - v_{sys}$; from an average of all available interstellar absorption lines) vs. galaxy rotation speed for the sources showing outflows. Disk galaxies (NGC 3310-ABC, NGC 5996, NGC 7552) are represented by stars (blue in the electronic edition); galaxies which are dwarfs by morphology but not by M_B (Mkn 33, NGC 5102, Tol 1924-416) are represented by a filled square (green). Dwarf galaxies are marked by filled triangles (red). NGC 1705 is marked by a filled circle (cyan; Vázquez et al. 2004). The error bars from the STIS data represent the velocity fitting error as discussed in §3.1. The dotted (red) diagonal lines show the relations $v_{term} = \sqrt{2} v_{rot}$ (minimum escape velocity) and $3 v_{rot}$ (escape velocity at 3 kpc in an isothermal halo extending to 100 kpc). The solid (black) line shows a linear least squares fit to the data; its slope is 1.2 ± 0.2.

Fig. 10.— C II outflow velocity versus Al II (top) and Si II (bottom) outflow velocities. The ionization energy of carbon is 11.26 eV, whereas the ionization energy of aluminum (silicon) is 5.99 eV (8.15 eV). The diagonal (dotted) lines represent $v_{CII} = v_{AlII}$ and $v_{CII} = v_{SiII}$. The least-squares fits of the lines give slopes of 0.77 ± 0.15 (0.61 ± 0.13) for Al II (Si II).

Fig. 11.— (a) Normalized STIS spectra of the low ionization absorption line profiles used to measure the warm/cold gas outflow velocity in NGC 4214, Region 1. The solid (red in the electronic edition) line plotted over the data is the fit from the SPECFIT program. The dotted lines represent the wavelengths corresponding to the systemic velocity for each of the absorption lines, which are labelled with the species and ionization state. The systemic velocity is 304 km s^{-1} (Becker et al. 1995), which agrees with stellar lines seen in optical (Schwartz & Martin 2004) and UV (this paper). The measured line velocity is -32 ± 49 km s^{-1}, which is consistent with the findings of Schwartz & Martin 2004 that no outflow is detected in optical resonance absorption lines in Region 1. (b) Normalized Na I Keck I/HIRES optical resonance absorption spectrum for NGC 4214-1 (Schwartz & Martin 2004). The doublet lines are marked D1 (λ5889.95) and D2 (λ5895.92). (c) Same as (b), for NGC 4214-2. Cold, interstellar gas is seen in absorption and is blueshifted from the systemic velocity by 23 km s^{-1}.

Fig. 12.— Outflow velocity ($\Delta v_{outflow} = v_{line} - v_{sys}$; from an average of all available interstellar absorption lines) vs. star formation rate as calculated from Hα luminosity using equation 2. The error bars represent the velocity fitting error as discussed in §3.1. Data point symbols and colors are the same as in Figure 9. The Hα luminosities have not been corrected for internal extinction, which would increase the luminosity (and therefore the SFR) by ∼50%. The data point with the lowest SFR, NGC 5102, is a lower limit on SFR because the Hα luminosity is that of the nucleus only. The solid line is a least-squares fit to the data (excepting NGC 5102); the slope is 0.51 ± 0.59.

Fig. 13.— (Top) Composite rest-frame UV spectrum of 811 Lyman Break Galaxies from Shapley et al. (2003); resolution ∼2.8 Å. (Bottom) Composite rest-frame UV spectrum of the 16 star-forming clusters in our sample; resolution ∼2.9 Å. The solid (colored blue in the electronic edition) lines represent the wavelengths of stellar lines, the dashed (red) lines are are predominantly interstellar in origin, and the dotted (green) lines are the high-ionization Si IV and C IV doublets, which are blends of the gas in stellar photospheres/winds, and possibly some interstellar gas.

Fig. 14.— Distribution of UV luminosities (L_{UV}; ergs s^{-1} Å^{-1}) for the local sample ($L_{UV} <$ 10^{40}; solid bold line – red in the electronic edition) and the LBG sample (log $L_{UV} > 10^{40}$; Shapley et al. 2003; dashed line – blue in the electronic edition).

This figure "f12_color.gif" is available in "gif" format from:

http://arXiv.org/ps/astro-ph/0605215v1